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ELUTRIATOR/MICROCOSM SYSTEM
Pilot Model and Test

by

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An effective technique is described for transferring soft benthic sediments with their resident infauna intact into special holding systems (elutriator/microcosms) which permitted the study under controlled conditions of both nutrient exchange from the sediments and the activities of their infaunal communities. The effects of bioturbic activity on nutrient exchange rates could not be detected by water column measurements but could be seen using a specially developed micro-coring technique. Alpheid shrimp activity was estimated to increase the sediment surface area by 2- or 3-fold and also tended to mask signs of burrowing by smaller infaunal animals. An increase in infaunal population after sediment transfer to a clean-water situation suggested that the sediment itself was acting like an analogue to an "artificial reef". Continued investigation of this "artificial-reef effect" is recommended.

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LIST OF ABBREVIATIONS AND SYMBOLS

ABS = acrylonitrile-butadiene-styrene
cm = centimeter
E/M = elutriator/microcosm, see page 5 of text
GF/C = glass fiber/coarse
gpd = gallons per day
HCZDB = Hawaii Coastal Zone Data Bank
HIMB = Hawaii Institute of Marine Biology
hr = hour
l = liter
lpm = liter per minute
LRT-box = long-residence-time "inlet box", see page 6 of text
m = meter
ml = milliliter
mm = millimeter
MSL = Mean Sea Level
NUC = Naval Undersea Center (now Naval Ocean Systems Center)
ppm = parts per million
PVC = polyvinyl-chloride
rpm = revolutions per minute
std = standard
TN = Technical Note, an informal NUC publication
TP = Technical Publication, a formal NUC publication

ug-at/l = microgram-atom per liter

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SECTION 1

INTRODUCTION

As a result of several environmental studies (1-3), the City & County of Honolulu decided to terminate all sewage discharges into Kaneohe Bay, Oahu. A new outfall with diffusers located from 1250 m to 1543 m offshore of Mokapu Point at mean depths ranging from 27 m to 32 m below MSL[a] is presently under construction. All discharges are expected to be diverted to this new outfall in August of 1977. As a result, an estimated 19 x 10^3 m^3 per day (5.0 mgd) of secondary-treated sewage will cease to flow into Kaneohe Bay. This event provides an excellent opportunity to determine the response of an Hawaiian estuary to an abrupt change in nutrient supply. Similar sewage-removal actions by the Navy in Pearl Harbor can be used to augment the basis of such a study. Since Navy ships can represent a sewage impact to harbors and estuaries, it is in the Navy's interest to understand the full nature of sewage impact (both positive and negative) on confined marine environments. In consequence, the Kaneohe Bay Sewage Relaxation Study (4) was organized as part of a larger cooperative effort (5) between the Hawaii Institute of Marine Biology (HIMB) and the Naval Undersea Center (NUC).

Since Kaneohe Bay has been receiving increasing amounts of sewage over the past several decades, a considerable nutrient reservoir has accumulated in its sediments. The size of this reservoir and the exchange rates into and out of it are an important aspect of the Sewage Relaxation Study. Although field surveys by HIMB are currently in progress to determine reservoir size and location, it is also necessary to conduct controlled experiments to obtain accurate information on nutrient exchange rates, and how such rates are influenced by biological activity, such as turnover by polychaetes (6) or by mechanical disturbances, such as tidal currents or stirring by ships' propellers (7).

This project was undertaken in response to the second requirement stated above. Its objectives were to develop and test techniques and equipment suitable for transferring sediments with their resident infaunal communities intact from Kaneohe Bay to the NUC microcosm facility at Ulupau. In addition, tanks at the Ulupau facility were converted into pilot models of elutriator/microcosms (E/M). The transferred communities were maintained in these E/Ms for periods exceeding 90 days both to test the models themselves and to assure that the communities exhibited normal activity after transfer. Subsequent projects would determine the nutrient status of the sediments and the effects of bioturbic activity on nutrient exchange rates under controlled conditions.

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[a] See list of abbreviations and symbols.

SECTION 2

CONCLUSIONS

Two methods of transferring soft-bottom communities from Kaneohe Bay to the Ulupau microcosm facility were tested. Two different pilot models of elutriator/microcosms (E/M) were constructed and tested. Both transfer methods were judged successful as evidenced by representative community capture and by continuing normal infaunal activity for over 90 days. A simple bucket-scoop collection procedure was perfected and used for both types of transfer, namely direct, in which the buckets themselves were moved into the E/M tanks, or indirect, in which the bucket contents were transferred to polyethylene trays, which were subsequently placed in the E/M tanks. The second procedure and E/M design were preferred because the intermediate transfer gave no evidence of increased stress to infaunal organisms and because a larger sample of the bottom community could be moved and uniformly distributed about the E/M tank.

Efficiency of capture was determined by estimating the number of alpheid shrimp (*Alpheus mackayi*) per unit area of bottom in the field and by counting the number found in the transferred communities. Observations of the captured shrimp showed that between 3 and 5% of the burrows, as determined by counting entrances, were occupied. In both transfer methods tested, the expected number of shrimp were captured. It was concluded that bucket-scoop procedure was a reasonably efficient collection method for the soft sediments of Kaneohe Bay, where shrimp usually do not penetrate deeper than about 10 cm.

Judging mainly from alpheid burrowing, the transferred community continued normal activity despite obvious changes in food availability, recruitment, and water quality. Certainly, the constant "rain" of organic detritus from the water column found by HIMB (8) to be characteristic of the Kaneohe Bay collection sites was absent in the E/M tanks. But either the transferred sediment itself contained sufficient food or an alternate source from the water column was employed since all 8 of the captured alpheids survived more than 90 days. Observation of the captured shrimp showed that their activity has pronounced effects on bottom micro-topography. Not only do they make numerous burrows (about 26 burrow entrances per shrimp), but they also mask the topographic signatures of smaller infaunal residents. Furthermore, either their grazing or their crawling over the surface removes a brownish diatom matte which tends to form over the sediment. Similar matte removal has been reported by Reise (9). It can be concluded that certain infaunal inhabitants cannot be detected by scuba inspection of the bottom since micro-topographic evidence of their presence can be masked by the activities of other residents.

The transferred communities can be maintained in flow-through E/M tanks for periods well in excess of 90 days. Such maintenance times are certainly sufficient to conduct controlled experiments on sediment exchange rates. Design and test of these E/M tanks and of the transfer methods constitute the principal objectives of this project. Details are presented in Sections 4 and 5.

Certain additional observations using these transferred communities have also been included in this report. Increased nutrient concentrations (ammonia-N, nitrate-N, phosphate-P, and silicate-Si) could not be detected in E/M flow-through waters even though the captured alpheid shrimp caused considerable sediment disturbance. Their burrowing activity was estimated to have increased the sediment-water interface area by 2- or 3-fold, in addition to the amount of sediment suspended as a result of excavation. No statistically significant differences in nutrient concentrations were observed between E/M outlet waters and water samples taken 15 cm above the bottom at either collection site in Kaneohe Bay. These observations suggest that sediment-to-water exchange rates in the E/Ms may approximate steady state conditions in the field. That loss of nutrients from the sediment was occurring could be shown by micro-coring techniques developed when water-column measurements failed. Micro-cores established that, for ammonia-N at least, there was a decrease in interstitial water concentrations as the sediment surface was approached, implying that either surface exchange or bacterial regeneration was taking place.

The resident infaunal populations were observed to increase approximately 10-fold during the 92 to 135 day periods that the transferred sediments were maintained in the Ulupau microcosm facility. This increased population occurred despite the fact that the transferred sediments would have to be classified as "nutrient polluted" on the basis of the Corps of Engineers standard elutriation test (10, 11). It should be emphasized that these sediments did not cause observable increases in the nutrient concentrations of E/M flow-through waters. Although these preliminary observations must be substantiated with further controlled experiments, they do suggest that nutrient-rich sediments can appear to act as an analogue to an "artificial reef". If similar population increases can be demonstrated for sediments classified as polluted by heavy metals, presently accepted strictures on the disposition of such dredge materials would require re-examination.

Finally, an inverse of the infaunal response has been observed in fouling panels or wood block communities when subjected to the same transfer conditions (12). These populations decrease, apparently through starvation, rather than increase. Use of both sediments and fouling panels in simultaneous transfer experiments can, therefore, complement each other in the systematic search of bioindicators of water quality.

SECTION 3

RECOMMENDATIONS

Bucket-scoop collection procedure with intermediate transfer to polyethylene trays should be used in future sediment collections. Further experiments using the second E/M design are recommended to determine the effect of bioturbic activity on nutrient exchange rates. Since monitoring the water column for nutrients was shown to be insensitive, these further investigations should exploit micro-coring techniques described in Section 4. Such techniques might be profitably augmented by nutrient measurements within the burrow tunnels. Use of quick-setting epoxy resins to determine burrow dimensions would improve estimates of sediment/seawater interface areas.

Of greater interest is the observed increase in infaunal populations when nutrient-rich sediments are transferred to an oceanic environment. This apparent "artificial reef" effect deserves continued study since it could relate directly to dredge material disposal problems. Such research should involve transfers of sediments from various locations both to the E/Ms already established at the NUC facility and also to similar E/Ms which could be established at MLMB. Collection locations should include harbors known to be polluted with heavy metals. Finer screening of both field and E/M sediments is recommendnd to obtain better data on population changes resulting from transfer. Since fouling panel and wood block communities show population decreases after transfer (an inverse response to that observed in nutrient-rich sediments), further research is recommended to exploit these differences.

SECTION 4

MATERIALS AND METHODS

GENERAL STATEMENT

Stated project objectives required (a) the design and testing of field collection and transport techniques capable of obtaining representative, yet relatively undisturbed, samples of sediments with their infaunal communities intact, and (b) the design and operation of a holding system which could maintain the collected communities in a healthy, active state. Therefore, this section, rather than those which follow, contains the required project output.

PILOT ELUTRIATOR/MICROCOSM (E/M) DESIGN

Microcosm Facility

An existing microcosm facility constructed by NUC at Ulupau (Figure 1) and described in detail elsewhere (5, 12) was used as the basis for the holding system. Briefly, this facility consists of twelve 600-liter fiberglass tanks with gel-coated surfaces continuously supplied with unfiltered, oceanic or low-nutrient seawater at any desired rate up to 10 lpm[a]. With the exception of titanium pump shaft sleeves, all materials used in the seawater distribution system are of plastic construction. Piping and fittings are PVC[a] plastic; four 3-inch Y-fittings in the main supply pipes are ABS[a] plastic. The entire seawater distribution system is double plumbed, and is kept free of filter-feeding organisms by alternating between the two systems at weekly intervals. The unused system is allowed to become anoxic, thus freeing it of any organisms that settled during the previous 7-day period of use. Organic debris is back-flushed out of the system just prior to putting it back into operation.

Elutriator/Microcosms

Two methods of holding sediment infaunal communities were tested. The first, a pilot model built to hold initial test collections, was a fiberglass tank, 119.4 x 58.4 x 47 cm deep, with a special diffuser inlet whose depth in the tank could be adjusted (Figure 2). Tank volume was 328 l and inlet box volume was 16 l. The tank was covered with four plys of 2-mm mesh, gray plastic screen, which reduced light in the tank to 12½% of ambient daylight. This was done to approximate the reduced lighting con-

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[a] See list of abbreviations and symbols.

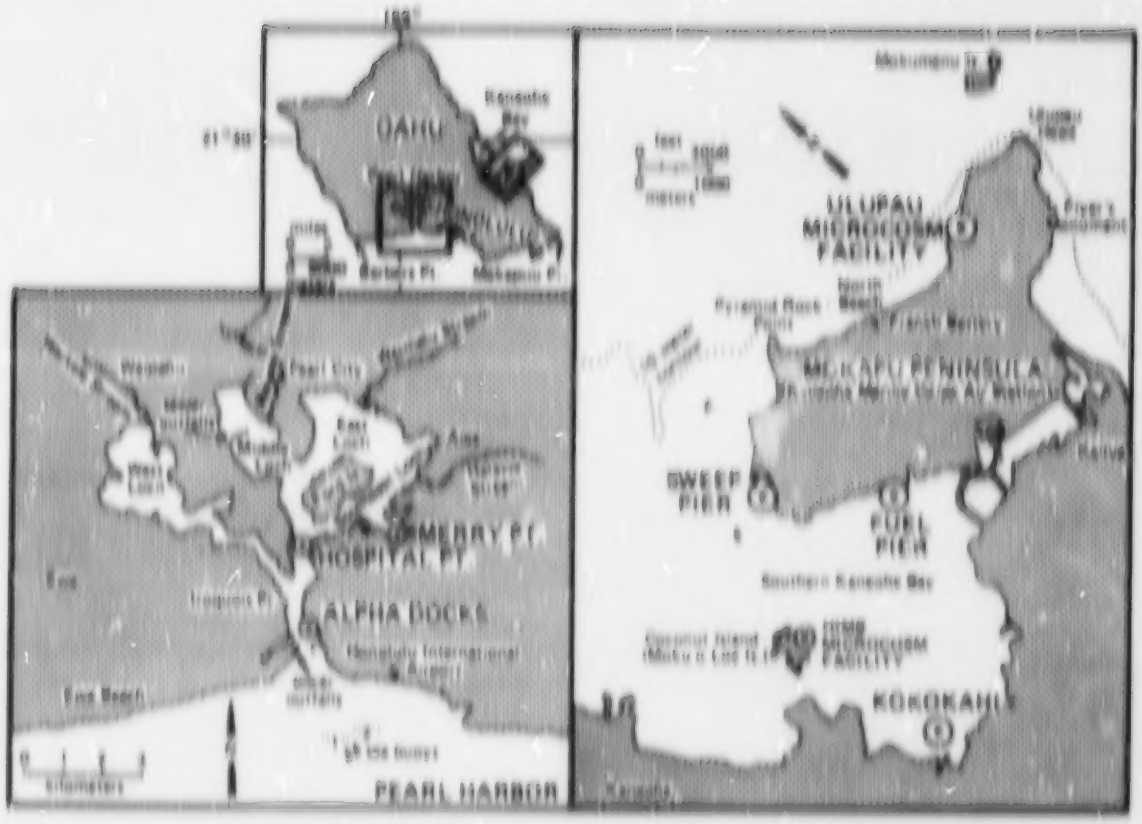

Figure 1. Location of Ulupau Microcosm Facility and Field Collection Sites

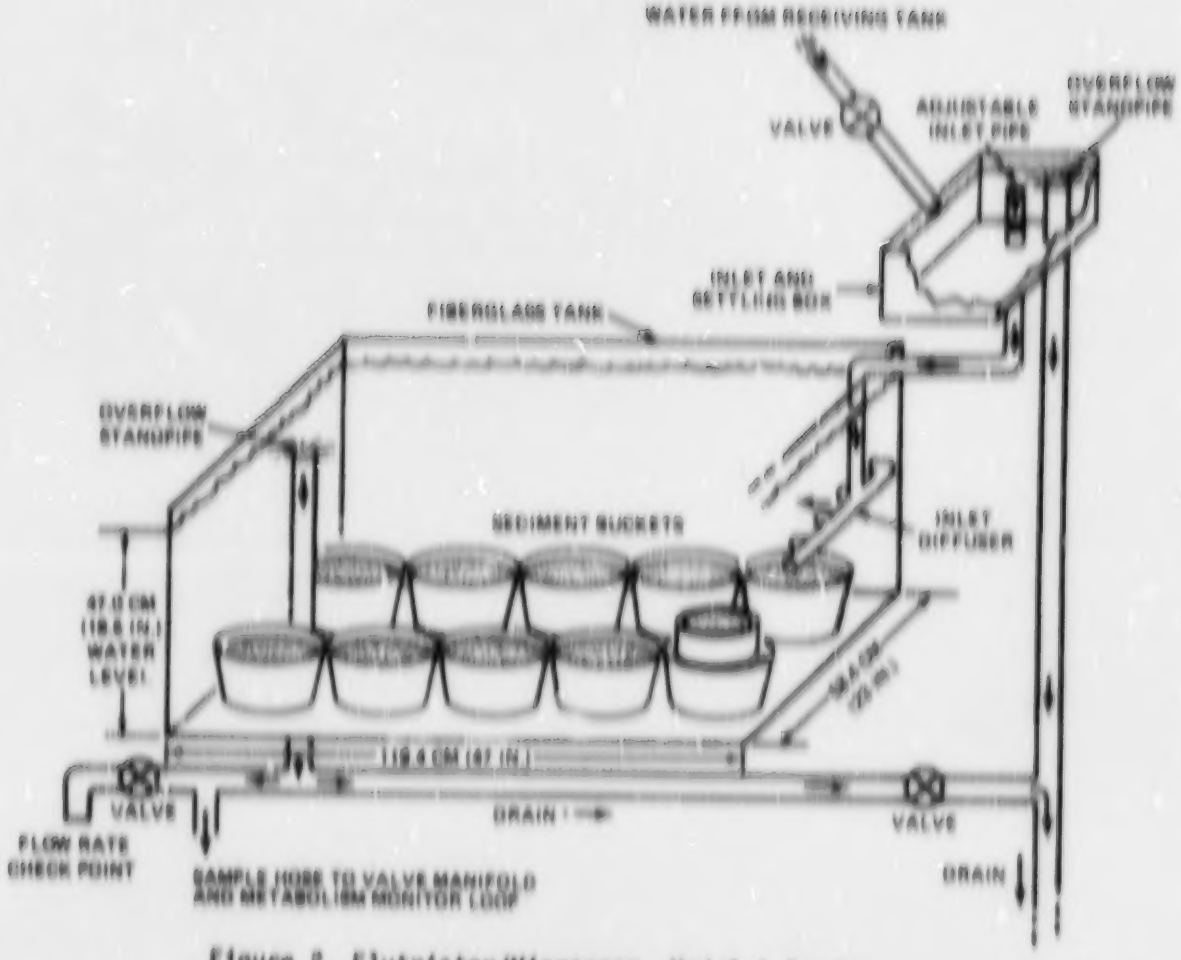

Figure 2. Elutriator/Microcosm, Model-1 Design Used to Hold the Kokokahi Sediment Collection

ditions at the bottom of Kaneohe Bay. Transferred sediment was placed on the bottom of this tank in nine plastic buckets containing 4.7 l each and in a coring device holding a 23-cm core representing 7.4 l. In all, the tank contained 50 l of sediment in a seawater volume of 270 l. The planar area of the sediment was about 0.1 m^2 (2000 cm^2); the true surface or sediment/seawater interface is estimated to be 2- or 3-fold greater (see discussion in Section 6). Flow rates through the tank were varied from 13 lpm to 0.6 lpm. In general, ambient conditions at the collection site were closely approximated by this holding system (hereafter called the model-1 elutriator/microcosm or E/M). No attempt, however, was made to simulate hydrostatic pressure or nutrient status of the water. These departures from conditions at the collection site do not appear to have serious consequences. After a 135-day test, the greater depth and the adjustable diffuser of the first E/M model did not appear to be required, thus a second and simpler model E/M was tested.

The second or model-2 E/M used one of the existing microcosm tanks. These were 117-cm square fiberglass tanks, 41 cm deep and containing 555 l of seawater (Figure 3). As with the first E/M, the tank was covered with 4 plys of screen, reducing the light to 12% of ambient daylight for the first 27 days; thereafter a completely opaque cover was used. The bottom of the E/M was "lined" with 7 high-density black polyethylene trays[a] (dimensions: 46.7 x 30.8 x 10.5 cm deep), containing 14 l of sediment each. These boxes covered 74% of the E/M bottom, the remaining area about inlets and outlets being filled with clean carbonate beach sand. The E/M contained 100 l of sediment in a seawater volume of 455 l. Planar sediment area was about 1 m^2 (10,000 cm^2). Flow rates were varied from 9.6 lpm to 0.6 lpm. Again, no attempt was made to simulate either hydrostatic pressure or nutrient status of the water at the collection site.

Supply Water Problems

The nitrogen content of supply waters at Ulupau varies considerably with the state of tide and surf (Figure 4). These variations are thought to result from nitrogen fixation by blue-green algae in a shallow lens of seawater which remains nearly stationary over the reef flat during low-tide, low-surf conditions. As the tide rises, this nitrogen-enriched lens is swept by surf and winds into the Ulupau intake system. In an attempt to damp this short-period nutrient "noise", a second microcosm tank (550 l) was plumbed to operate as a long-residence-time "inlet box" or LRT-box (Figure 5). Both the LRT-box and the model-2 E/M were fitted with opaque covers. The mean residence time of water in the LRT-box was calculated to be about 15 hr, or greater than the tidal cycle (12.4 hr). This modification, made 27 days after the second sediment transfer and continued for the remainder of that experiment, failed to damp variations in nitrogen concentration and apparently increased the ammonia content of the supply waters (see section 5).

[a] Distributed under the name "tote box" by United States Plastics Corporation, Lima, Ohio.

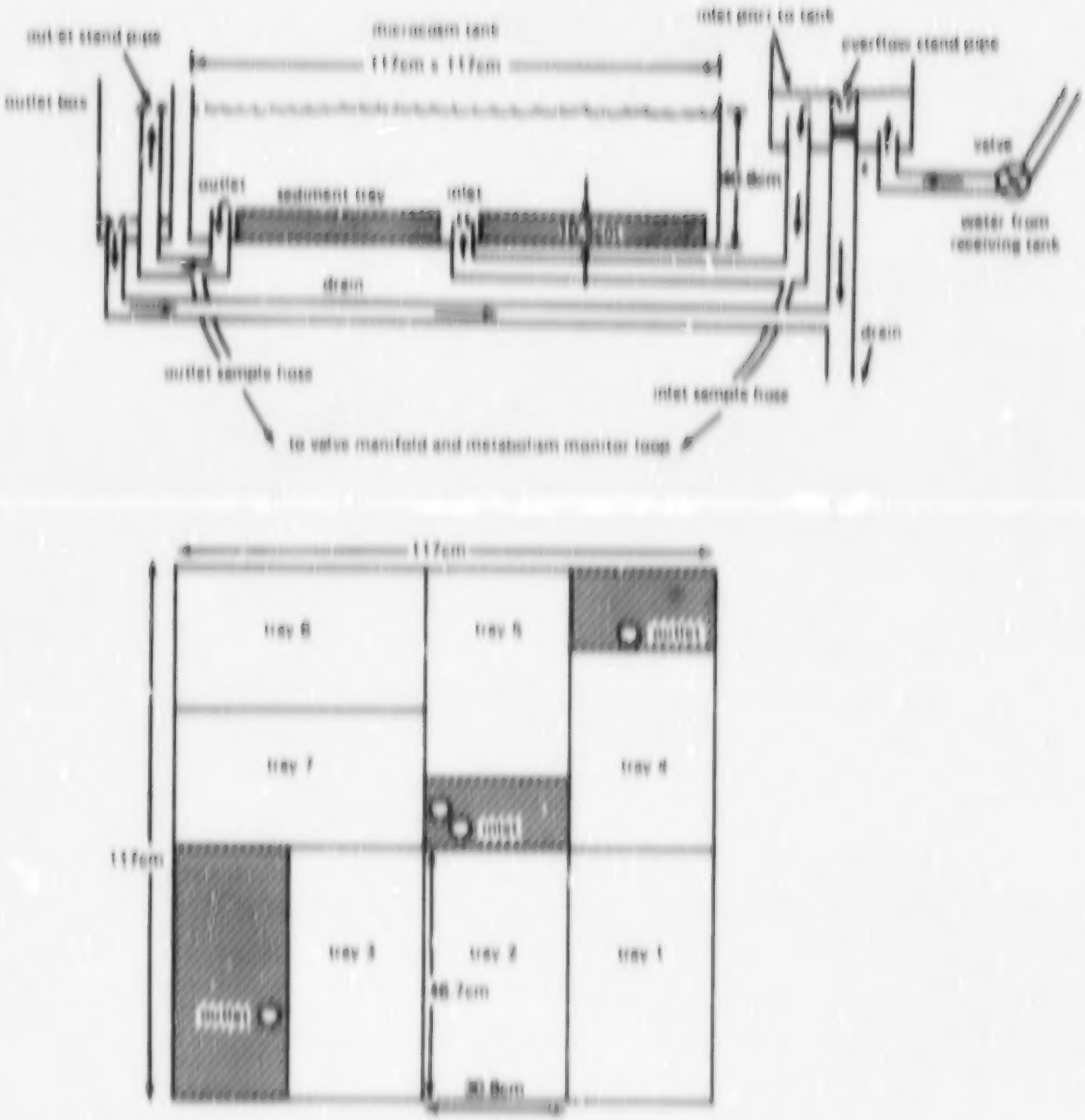

Figure 3. Elutriator/Microcosm, Model-2 Design
Used to Hold Fuel Pier Sediment Collection

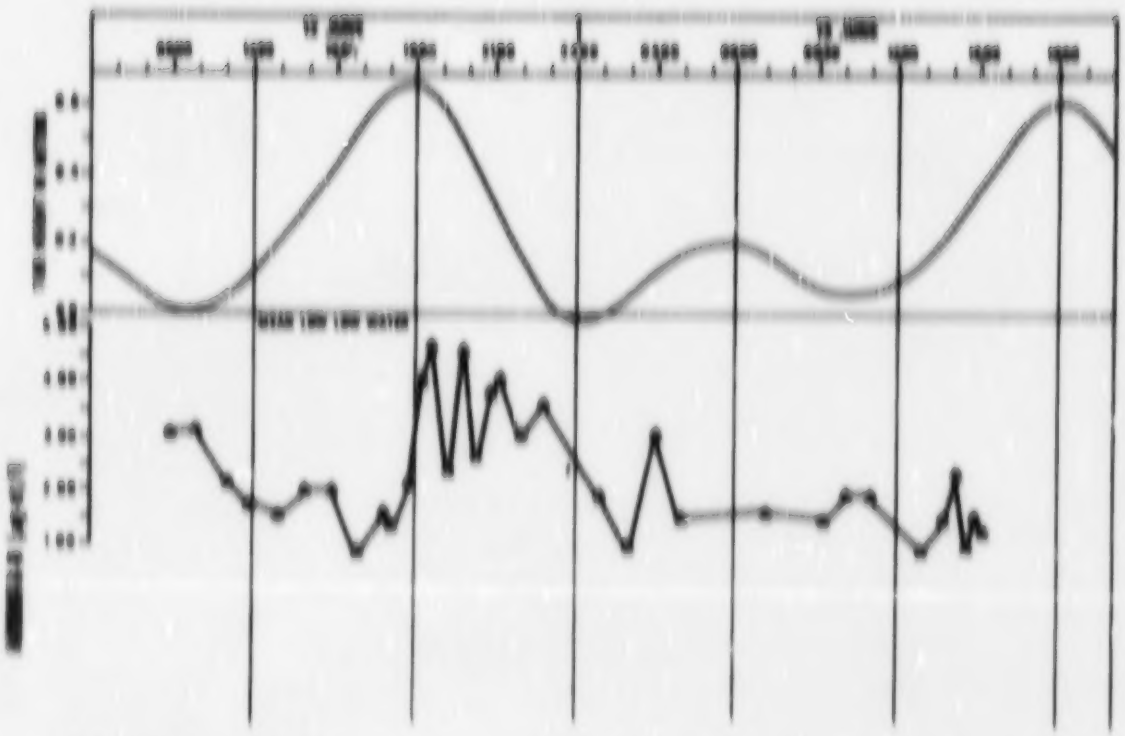

Figure 4. Inlet Water Concentrations of Ammonia-N versus Time and Tide for Ulupau Microcosm Facility, 12-13 June 1975

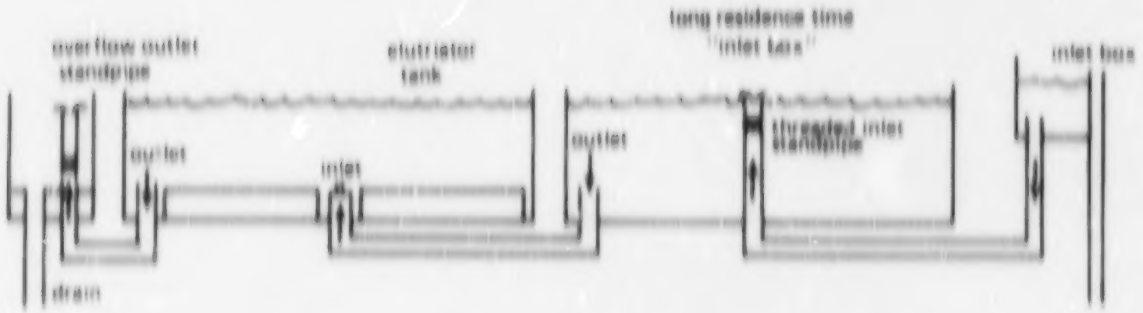

Figure 5. Ganged Microcosm Arrangement to Create a Long-Residence-Time "Inlet Box" (LRT-Box)

COLLECTION AND SUPPORT EQUIPMENT

Collection Equipment

The soft bottom muds at the two collection sites did not require specialized equipment. Collection was made by two scuba divers using plastic buckets (mean diameter = 19.0 cm, depth = 17.8 cm, volume when filled to within 1 cm of the top = 4.7 l) and a large corer (20.3-cm inner diameter x 24 cm long). The buckets were scooped in a smooth arc through the top 10 centimeters of sediment. The large corer was used to collect minimally disturbed sediment to a depth of 24 cm. It consisted of a PVC pipe (outer diameter = 21.6 cm) with one end beveled into a cutting edge. Both ends of the corer received snap caps which provided a tight seal. This device was slowly pushed into the sediment by a scuba diver. The device was then rotated to shear the core and tilted about 10° to create a water passage. A cap was then slid down this passage and worked onto the bottom of the corer. The top was then capped and the corer was carefully withdrawn from the sediment.

Larger, 14-liter buckets (mean diameter = 28 cm, depth = 28 cm) were used in the second collection. Again these buckets were scooped in a smooth arc through the top 20 cm of sediment by scuba divers operating on the bottom. After thus being filled, the bucket was hauled to the surface. Its contents were then "slid" with minimal disturbance into a polyethylene tray, previously described. One bucket just filled a tray to within a centimeter of its rim.

Transport Equipment

Transport equipment was simple. The buckets and the large corer were moved on flat plastic trays to catch splash or slop. To minimize disturbance during transport, only a 5-mm film of seawater was left covering the sediment samples which were kept shaded and shielded from the wind at all times. The polyethylene trays stacked in a manner which sealed them. These were moved in tiers of 3 or 4 trays at a time. Logistic equipment included a Boston whaler and a panel truck.

Other Coring Devices

Two other devices were used, namely a small corer and a micro-corer. The small corer (10.0 cm diameter x 65 cm long) was used to observe stratification and depth of burrowing at the field collection sites. This corer was also a piece of PVC pipe pushed by a scuba diver into the soft bottom. The exposed end was then capped and the whole device twisted & tilted to break suction before removal. At the surface, a plunger was inserted to extrude the core for inspection. For the sediments sampled in Kaneohe Bay, good cores of 40 to 60 cm in length could be obtained.

A micro-corer (Figure 6) was used to obtain samples of interstitial water for nutrient analysis. This corer consisted of a 2.3 cm diameter

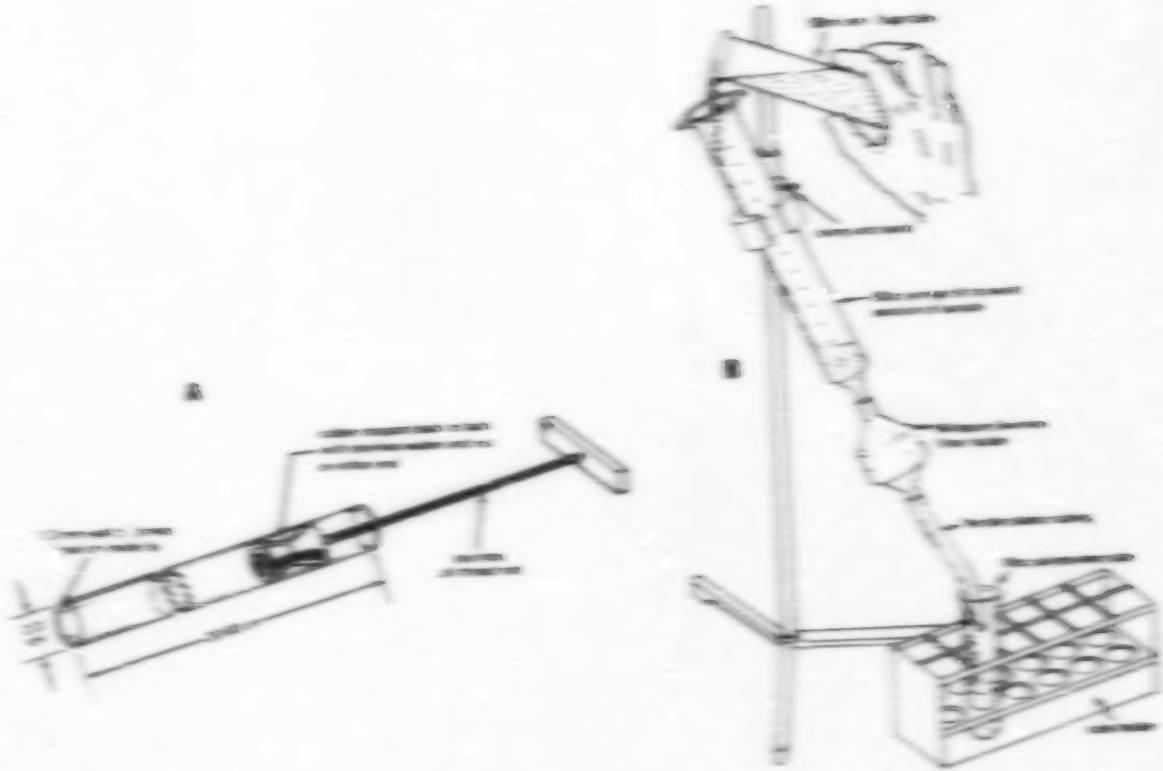

Figure 6. Micro-coring Apparatus: (A) Micro-corer, (B) Filter Apparatus for Interstitial Water Extractions

clear styrene tube, 20 to 60 cm long, depending on the length of core desired. This tube was fitted with a plunger and handle. The mouth of this micro-corer with the plunger fully inserted was placed gently on the sediment surface by a scuba diver. The plunger handle was held steady at a fixed elevation above the sediment while the tube was pushed into the bottom as far as possible. The tube was twisted approximately 360° to shear the core free, then tilted 10° to 30° *off* vertical while still *in situ* to create water passage to the base of the core. After tilting, the core was pulled free of the bottom. In transit, both ends of the micro-corer were plugged with rubber stoppers and the whole was stored on ice in a cooler.

SECTION 6

EXPERIMENTAL PROCEDURES

COLLECTION, TRANSPORT, AND HOLDING OPERATIONS

Experimental procedures are presented, in part, in the preceeding section because the simple material and methods employed are better understood if accompanied by some description. Some results influencing the field procedures are better presented here than in the following section. Laboratory and E/M results are to be found in Section 6.

Before any collection was made, the topography of the bottom was carefully inspected by a pair of scuba divers. This inspection was used to estimate the density of alpheid shrimp in residence at the collection site. Ten-cm cores to the maximum depth possible were made & inspected at the site to determine both strata and the depth of alpheid burrowing activity. After inspection, the upper or occupied sections of these cores plus additional scoop collections were rinsed through a 1-mm mesh screen to obtain a sample of the resident infaunal population. All organisms found were returned to the laboratory for complete identification.

As mentioned previously, a 5-mm film of seawater was left covering all sediment samples during transport to the E/Ms at Ulupau. Samples were kept shaded and shielded from the wind at all times. Temperature shock did not constitute a problem since water and air temperatures were nearly the same. The entire operation (collection, transport, and installation in the E/Ms) took approximately one hour.

Kokokahi Sediments

On 14 January 1976, the first sediment collection was made in 10 m of water at a site 200 m northeast of Kokokahi Pier (Figure 1). This site was approximately 500 m east of the Kaneohe sewage treatment plant outfall. This outfall discharged 13.2×10^3 m^3 per day (3.5 mgd) of secondary-treated sewage. The bottom was soft, reddish-brown silt which appeared largely terrigenous in origin. Alpheid shrimp burrows (probably *Alpheus makay*), ranging from 1 to 5 cm in diameter, were dominant; burrow spacing was about 8 cm, or about 200 burrows/m^2. Nine 19-cm buckets were filled by the bucket-scoop method and a single 24 cm core was obtained with the large corer. Total volume of sediment collected was 50 l. The bottom area covered was about 0.3 m^2 (2889 cm^2), an area that should have intercepted about 57 shrimp burrows. As reported in Section 6, between 3 and 5% of the burrows

are occupied; therefore, about 2 or 3 shrimp would have been expected. Although this first capture was low, subsequent collections yielded the expected number of shrimp.

A 56-cm core was obtained using the small corer. This core was extruded, sliced lengthwise, and inspected for stratification and burrows. The top 10 cm exhibited a layered fine structure; at about 30 cm the reddish-brown color of the silt darkened, becoming quite black in the last 20 cm of the core. Shrimp burrowing activity was confined to the aerobic top 10 cm. An additional volume of 13.2 l of sediment was collected by the bucket-scoop method and washed through a 1-mm mesh screen. All organisms found were returned to the laboratory for identification. A single shrimp, *Alpheus mackayi*, found in the top 10 cm of the 56-cm core was added to the infaunal population installed in the E/M.

The 9 buckets and the large corer filled with Kokokahi sediment were transported to Ulupau where they were placed in the model-1 E/M (Figure 2). Tank flow rate was set at 13 lpm the first day, but then reduced to 5 lpm for the next 50 days. Since no elevated nutrient concentrations could be detected in the E/M flow-through waters, the flow was further reduced to 0.6 lpm on day-51 day and continued at that rate for the remainder of the 135-day experiment (14 January to 28 May).

Inlet and outlet waters from the E/M were sampled twice daily, roughly at 0900 and 1500 hours. Samples were analyzed primarily for ammonia-N, but occasionally for other nutrients (nitrate-N, phosphate-P, and silicate-Si). Nutrient analyses are described in greater detail later. During the second through the fourth day of E/M operation, outlet waters did show a 1.7-fold increase in ammonia-N concentration ($P = 0.01$):

inlet ammonia-N (ug-at/l) = 0.50 ±0.05 (5)[a]
outlet ammonia-N (ug-at/l) = 0.83 ±0.09 (5),

this elevated ammonia-N concentration may have been associated with the installation of the sediment buckets, since at no other time during the 135-day run was any statistically significant difference shown between inlet and outlet nutrient concentrations.

Net oxygen production in the E/M tank was measured regularly about 1300, using a Yellow Springs Instruments Model 54 oxygen meter. Net oxygen change (ΔO_2) in the waters transiting the tank is considered one of a set of parameters measuring community metabolism of the E/M residents. Oxygen content of the supply waters at Ulupau ranges between 6.5 and 7.0 ppm. Under reduced sunlight (1/4 of ambient) net oxygen change tended to be negative (ΔO_2 (ppm) = -0.12 ±0.04 (16)) as a result of de-aeration and a slight amount of respiration.

Of major importance in this pilot study were daily observations to determine whether the captured infaunal populations continued normal activity. These observations together with a discussion of same are reported in Section 6. At the termination of the 135-day run, buckets B-1, B-2 and the corer (total sediment volume = 16.9 l) were washed through a 1-mm mesh

[a] Standard format: mean ± standard error of the mean (number of cases).

screen to recover the resident population. The remaining sediment was washed through a 2-mm screen to obtain the larger organisms only (alpheids and larger worms). Nothing was found on the 2-mm screen. All organisms recovered were sent to the laboratory for proper identification.

Fuel Pier Sediments

On 17 to 19 February 1976, microcosm tank #3 at Ulupau was drained, all material in the tank was removed, and the walls were scraped and washed with 4 N hydrochloric acid. The tank was converted to a model-2 E/M (Figure 3) by fitting it with a screen cover reducing illumination to 12½% of ambient sunlight. Seawater flow was resumed at 9.6 lpm and net change in oxygen concentration of waters transitting the E/M was determined at 1300 on both 20 and 23 February. That the E/M was nearly free of marine life was shown by the fact that the ΔO_2 values were close to zero, namely -0.35 and -0.20 ppm.

On 26 February 1976, the second sediment collection was made in 10 m of water at a site 5 m west of the Fuel Pier on the Marine Corps Air Station, Kaneohe (Figure 1). The bottom was soft and chalky in color, being largely calcareous silt. Shrimp burrows (*A. nuuhiyi*) were 1 to 2 cm in diameter and spaced 8 to 10 cm apart (approximately 160 burrows/m^2). Seven polyethylene trays were filled with sediment using the second collection method described in Section 4. Total volume of sediment collected was 100 l. The bottom area covered was about 0.8 m^2 (8,250 cm^2), an area that should have intercepted about 130 burrows. Using the 3 to 5% burrow-occupancy figure, 4 to 6 shrimp should have been captured. Seven shrimp were recovered upon terminal inventory, 2 of which were obtained during coring operations. Thus, 5 shrimp, an expected number, were captured.

The small corer was used to obtain two cores 46 cm in length. These cores revealed the bottom to be an unstratified mixture of calcareous silt and rubble. A heavy layer of fragmented bivalve shells at 46 cm prevented further penetration. These cores (7.2 l of sediment) were washed through a 1-mm mesh screen. Two *A. nuuhiyi*, which were added to the polyethylene trays, were found. The remainder of the material retained on the screen was shell fragments.

The 7 trays were transported to Ulupau and installed in the model-2 E/M (Figures 3 and 7). Due to spread when transferred to the trays, planar area of sediment exposed in the E/M was about 1 m^2 (10,068 cm^2). Tank flow rate remained at 9.6 lpm for the first 8 days. Again in an attempt to detect enhanced nutrient losses, the flow rate was reduced on day-9 to 0.6 lpm where it remained for the duration of the 92-day run (26 February to 28 May).

As with the first E/M run, inlet and outlet waters were sampled twice daily, roughly at 0900 and 1500 hours, and analyzed as before. Like the Kokokahi run, net oxygen change in waters transitting the E/M was negative (ΔO_2 (ppm) = -0.16 ±0.11 (8)). Unlike the previous run, no significant increase in ammonia-N concentration in the outlet waters was observed shortly after sediment installation even though twice the volume of sedi-

Figure 7. Trays of Fuel Pier Sediment in Model-2 Elutriator/Microcosm Showing Alpheid Shrimp Burrows

ment was involved. On 24 March, when the E/M was covered with an opaque lid and also supplied with water from an LTR-box (Figure 6), inlet ammonia-N concentration more than doubled ($P = 0.01$) and was again increased 1.4-fold ($P = 0.05$) while transitting the E/M.

At the termination of the 92-day run, tray T-1 containing 14 l of sediment was washed through a series of screens, 0.5-mm, 1-mm, and 2-mm mesh. One *Bunce nodulosa* and 1 *A. makayi* were found on the 2-mm mesh screen. No organisms were found on either of the two smaller mesh sizes. Therefore, the remainder of the Fuel Pier sediment (86 l) was washed through the 2-mm mesh screen. One *A. makayi* was found in trays T-1, T-2, T-4, T-5, and T-7; 2 in T-6; and none in T-3. According to A. H. Banner (personal communication), intraspecific conflict between similarly sexed shrimp is common in *A. makayi*. Such conflict could determine the more or less regular spacing observed. All organisms recovered were sent to the laboratory for proper identification.

NUTRIENT ANALYSIS

Water Column Samples

Samples of inlet and outlet waters were regularly taken during both E/M experiments. In addition, simultaneous water samples were taken 15 cm below the surface and 15 cm above the bottom at both sediment collection sites, also at Sweep Pier in Kaneohe Bay and at Alpha Docks, Hospital Point, and Merry Point in Pearl Harbor (Figure 1). All samples were filtered through a 2.4-cm-diameter GF/C filter held in a Millipore "Swinnex" holder into 10-ml polystyrene vials which were capped with polyethylene lids and frozen immediately. Use of glass filters was found to be required in order to obtain valid ammonia determinations. They were therefore used even in the U.S. Army Corps of Engineers standard elutriation test although membrane filters are specified.

The samples were later thawed and processed for ammonia-N, nitrate-N, phosphate-P, and silicate-Si using standard techniques (14) with a Technicon II Autoanalyzer. For the ammonia-N analyses, great care was exercised in sample handling, laboratory cleanliness, and blank preparation. An internal standard was used and close control was maintained on instrument gain.

Micro-core Samples

Micro-cores were observed through the clear styrene tube walls for obvious stratification and resident fauna. Any water which had separated from the core was carefully decanted and filtered as already described. The cores were then extruded onto a clean surface and cut into segments (usually 5 to 10 cm in length). These were separately spooned into 50-ml round-bottom centrifuge tubes and centrifuged at approximately 3600 rpm for 6 to 12 minutes (maximum extraction volume was usually reached in 6 minutes). The supernate was decanted into a 50-ml syringe connected to a GF/C filter and filtered as described above (Figure 6B). Filter and holder were changed, and the whole apparatus thoroughly rinsed with filtered Ulupau

(oceanic) seawater between each extraction. Approximately 9 ml of each interstitial water sample was placed into a rinsed 10-ml vial, capped, and frozen until analysis.

Elutriation Test

On 16 August, 14-liters of sediment were collected using the bucket-scoop method at both the Kokokahi and the Fuel Pier collection sites. The collections from a given site were thoroughly mixed and 4 50-ml aliquots were taken for the elutriation tests. Four 200-ml aliquots of Ulupau Inlet water were also analyzed for nutrients. This water was used as the diluent in step (a) below. With the exception of the GF/C filters, procedure followed was that specified by the U.S. Army Corps of Engineers for the standard elutriation test (10, 11). The procedure is briefly summarized as follows:

(a) one part of sediment was combined with 4 parts by volume of Ulupau source water
(b) sediment and water were shaken mechanically for 30 minutes
(c) the mixture was allowed to settle for 60 minutes
(d) the supernate was decanted and filtered through an GF/C filter
(e) the filtrate was analyzed as described above for ammonia-N, nitrate-N, and phosphate-P.

If the concentration of a given moiety in the supernate from this test is more than 1.5-fold greater than that in the water column where the sediment is to be deposited (in this case, Ulupau), the sediment, according to the Corps, is classified as "polluted" in that moiety.

SECTION 6

RESULTS AND DISCUSSION

OBSERVATIONS OF INFAUNAL POPULATIONS

After transfer and installation of the sediments in an E/M, the resident organisms were observed daily for a period of 135 days in the case of the Kokokahi sediments and for 92 days in the case of the Fuel Pier sediments. Changes in the surface micro-topography proved to be a convenient method of recording shrimp activity and of inferring the general health of the community. These observations are best summarized in a series of sketches showing major surface features.

Kokokahi Sediments

Burrowing activity of the single *Alpheus mackayi* added from the small corer and the other residents collected at Kokokahi (see Section 5), and of the 14 *A. paetfloua* later added to the E/M may be followed in Figure 8. This figure shows the surface aspect of the sediment on days 1, 16, 26, 37, 106, and 135. *A. mackayi* makes round symmetrical burrow-entrances (Figure 9), while *A. paetfloua* makes asymmetrical entrances. The two types of entrances may be compared in Figure 8C. *A. paetfloua* are usually found in clean sand on the inner portion of exposed reef flats (15). They tend to burrow under solid objects because of the coarse-grained nature of their preferred substrate. Their preference for the sides of the buckets (Figure 8) may be linked to their field behavior. Depressions or "tracks", probably made by shrimp, are shown as dashed lines. Small mounds, probably made by annelids, are shown as parentheses. Micro-core sites are shown as triangles.

Note the large number of small mounds appearing on the first day (Figure 8A) which were quickly obliterated even though there was only one *A. mackayi* resident in the E/M. On day-16 (Figure 8B), this single shrimp has made a total of 18 burrow-entrances (roughly one a day) in only 2 of 10 possible sites, although the absence of the annelid mounds suggests that it has been active in all 10 containers. Figure 8C shows the surface aspect four days after two *A. paetfloua* had been added to the E/M. These shrimp were added to increase bioturbic activity in the hope that elevated nutrient concentrations would be detected in the flow-through waters. No increase in ammonia-N was detected. As they could be caught in the field, a total of 12 more *A. paetfloua* were added to the E/M (1 on day-26, 3 on day-27, and 8 on day-34). None of these additions caused any detectable in-

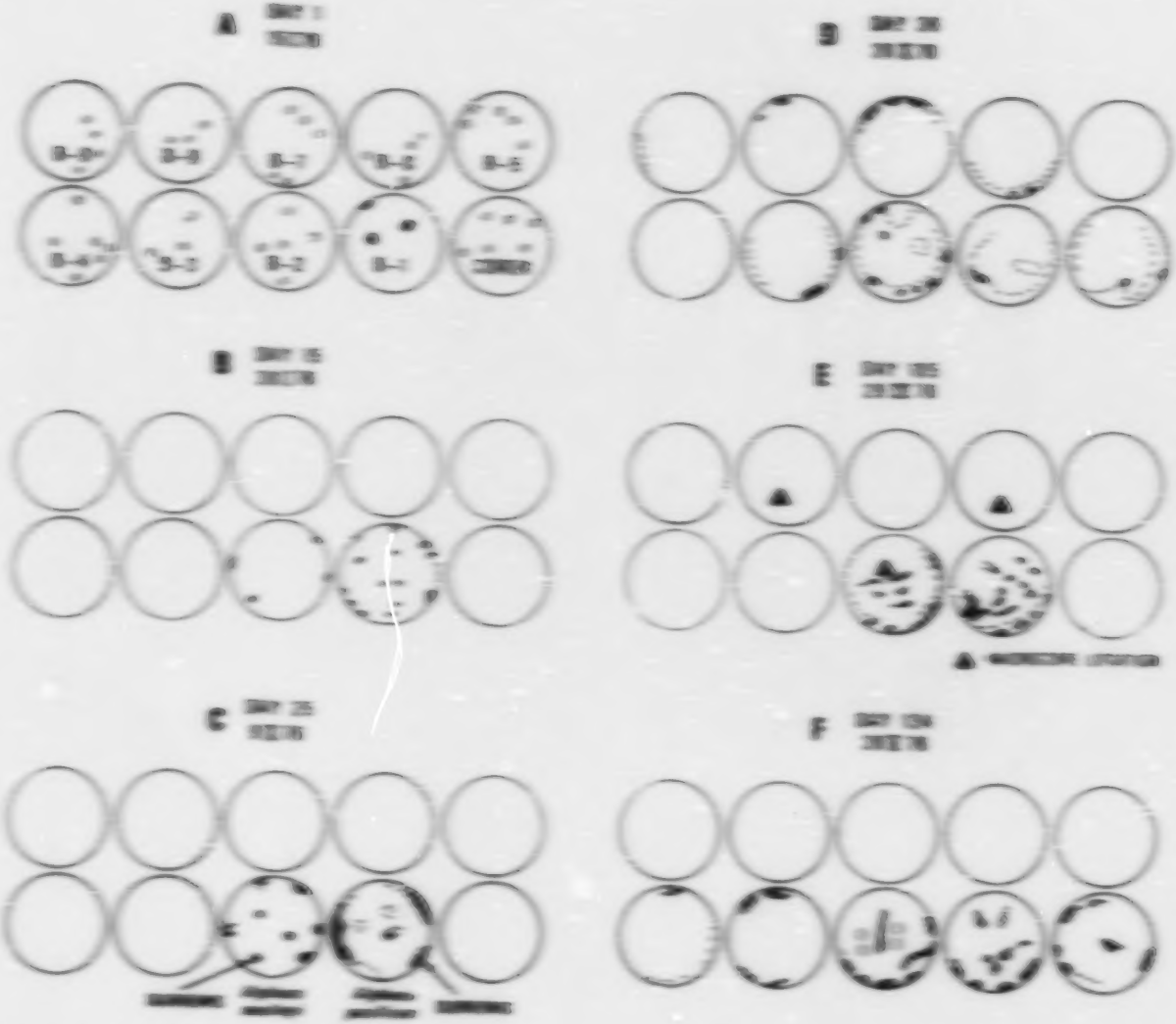

Figure 8. Sketch of Highfield Barrow Locations at Various Times during the Hoboken Sediment Experiment Micro-core Locations also Shown (see text for description)

Figure 9. Closeup of *Alpheus mackayi* Burrow Entrance

crease in outlet ammonia-N concentrations. Figure 8D shows an expansion of burrowing activity to a number of additional buckets, although the single *A. makayi* present seemed to confine most of his excavation to buckets B-1 and B-2. Sediment was daily thrown out of the buckets onto the floor of the E/M tank due to these excavations; this was allowed to lie there as a thin film. By day-36 all vestiges of the brown diatom matte was gone from all 10 containers. On day-51, the flow rate was reduced from 5 lpm to 0.6 lpm in an attempt to detect elevated nutrient concentrations. No increased ammonia-N levels were observed. Although the shape of the burrow entrances in Figure 8E indicated the continued presence of the single *A. makayi* in bucket B-1, it disappeared from the E/M shortly thereafter. This shrimp, together with most of the *A. pacifica*, probably passed out of the E/M on the flow-through current. Figure 8F (134 days) shows only *A. pacifica* to be present. Also shrimp activity was at this time sufficiently reduced so that smaller sediment surface features (not shown) were beginning to re-appear.

On 28 May, the Kokokahi E/M run was terminated. The E/M was dismantled and the sediment screened as described in Section 5. Two *A. pacifica*, as suggested by assymetry and number of burrows in Figure 8F, were found. All organisms recovered from the Kokokahi sediments are listed in Table 1.

TABLE 1. ORGANISMS FOUND IN KOKOKAHI SEDIMENTS AFTER 135 DAYS IN ULUPAU E/M (15.9 l of sediment)

HCEDB* #	Organism	Number Found		
		B-1	B-2	Corer
1052	Foraminiferida	2	2	3
374	Actiniaria	c	c	2
3763	Certantharia	1	-	-
51	Nematoda	1	-	c
551116	Hereidae	c	c	1
55112061123	*Lumbrineris heteropoda heteropoda* Marenzeller	1	-	-
55112061124	*Lumbrineris papillifera* Fauvel	1	-	c
55112061	*Lumbrineris* sp.	c	c	1
552	Sedentaria	c	c	1
552101	Spionidae	1	1	6
55210103	*Polydora* sp.	1	c	3
55211100101	*Prionospio alrivirga* Wiren	36	18	8
55211001101	*Polyophthalmus pictus* (Dujardin)	-	-	1
55211003102	*Armandia intermedia*	-	1	1
55211003	*Armandia* sp.	1	-	-
55211101	*Cirrosura* sp.	8	11	8
552113	Capitellidae	17	8	7

(continued)

* Hawaii Coastal Zone Data Bank identification numbers are used by a number of agencies performing environmental research in the Pacific Basin.

TABLE 1 (continued)

HCZDB #	Organism	Number Found B-1	B-2	Corer
55211701	*Sternaspis* sp.	-	58	-
552122	Terebellidae	-	-	1
554	Oligochaeta	2	2	-
644	Copepoda	1	1	2
6473040103	*Amphilochus neoshuna* Barnard	-	1	-
64730501	*Amphilochoides* sp.	1	-	-
6471250208	*Elasmopus pectinicrus* (Bates) Stebbing	11	-	1
64732505	*Maera* sp.	-	-	1
6473330201	*Jassa slatteryi* Barnard	-	-	2
6483411033	*Alpheus platyrhynchus* Dana	-	-	2
65	Insect larvae	1	-	-
7021	Archeogastropoda	1	-	1 f*
7021160101	*Triodella variabilis* (Pease)	-	-	1 j*
7022260109	*Rissoina multisona* Tomlin	1	-	-
70222601	*Rissoina* sp.	1 j*	-	-
70225601	*Triphora* sp.	1 f*	-	-
831	Ascidiacea	1	-	-
	TOTAL ORGANISMS	91	103	64

* f = fragment; j = juvenile form.

A total of 248 organisms were recovered from 16.9 l of sediment. From this total the 2 *A. platyrhynchus* should be subtracted since they were captured elsewhere and added. The organisms recovered from sediment screened at the Kokokahi site are presented in Table 2.

TABLE 2. ORGANISMS FOUND AT KOKOKAHI SITE
(13.2 l of sediment)

HCZDB #	Organism	Number and Remarks
55112061	*Lumbrineris* sp.	2
552	Polychaete fragment	1 with fragment of sand and mucus tube
552101	Spionid sp.	1
6483411002	*Alpheus mackayi* Banner & Banner	1, added from small corer
	TOTAL ORGANISMS	5

If the shrimp added from the small corer are subtracted, only 4 organisms were recovered from 13.2 l of Kokokahi sediment. The remaining

organic material on the screen was algal and terrestrial-plant fragments. To compare resident infaunal populations before and after E/M exposure, the 246 organisms found in the E/M sediments must be reduced to 192 to correct for the small difference between volumes screened. Thus, after a 135-day exposure to Ulupau source waters, the resident infauna per unit volume increased from 4 to 192 or about 50-fold. Some of this increased population was possibly only transitting the E/M. Certainly, this was the case for the *A. pacificus* (14 were added and only 2 were found in the terminal inventory). Based on what is known of the biology of the forms reported in Table 1 (16), the following organisms can probably be assumed to be transients. *Amphiloous* is associated with corals of the genus *Pocillopora*, that are abundant on the reef slope off Ulupau. *Elasmopus pocillopensus* is also associated with corals and coralline bottoms. The amphipods, *Amphithoe*, *Maera*, and *Jassa*, are usually associated with algae such as *Sargassum*, *Ulva*, and *Padina*, all of which are abundant on the Ulupau reef flats. A total of 17 more organisms could then be subtracted from the original count, thus bringing the corrected total to 179 for a 45-fold increase. While some of the remaining organisms may not be normal residents, certainly an order of magnitude increase in resident population would seem reasonable.

Several other features of the Kokokahi sediment run are noteworthy. Although the movement of reef organisms into the exposed sediment would tend to mask differences, the minimally disturbed sediment (core sample) compares favorably with the two scooped samples (B-1 and B-2). Secondly, shrimp activity caused pronounced alterations in the sediment surface in addition to the appearance of burrow entrances. Small features, such as the mounds and burrows of annelids, were masked and the brownish diatom matte that usually forms on undisturbed sediment surfaces was removed. Thirdly, the shrimp burrows themselves were estimated to increase the sediment/seawater interface 2- or 3-fold. This increased surface, plus the amounts of silt suspended as a result of such excavation, caused no detectable increase in the nutrient concentrations of E/M flow-through waters (see later discussion).

Fuel Pier Sediments

Burrowing activity for this second sediment transfer is presented in Figure 10. The surface aspect of the sediment is shown on days 1, 3, 10, and 27. The symbols are the same as those used for Kokokahi (see page 14). The sequence of observed events is also very similar.

On day-1, 14 burrows, a number of tracks, and many annelid mounds appeared. On day-3, over 70 obvious burrow entrances were counted. Shrimps, evidently *A. mackayi* by the shape of burrow entrances, had occupied all but trays T-3 and T-4 (tray numbers are given in Figure 3). Annelid mounds appeared only where shrimp were not active. Despite all this excavation, no increased nutrient concentrations in E/M flow-through waters were observed. On day-5, E/M flow rate was, therefore, reduced from 5 lpm to 0.6 lpm. Still no increased ammonia-N was detected. By day-10 (Figure 10C), one week later, the number of burrows had more than doubled. Tray T-3 was still unworked and still displayed annelid mounds. On day-27 (Figure 10D),

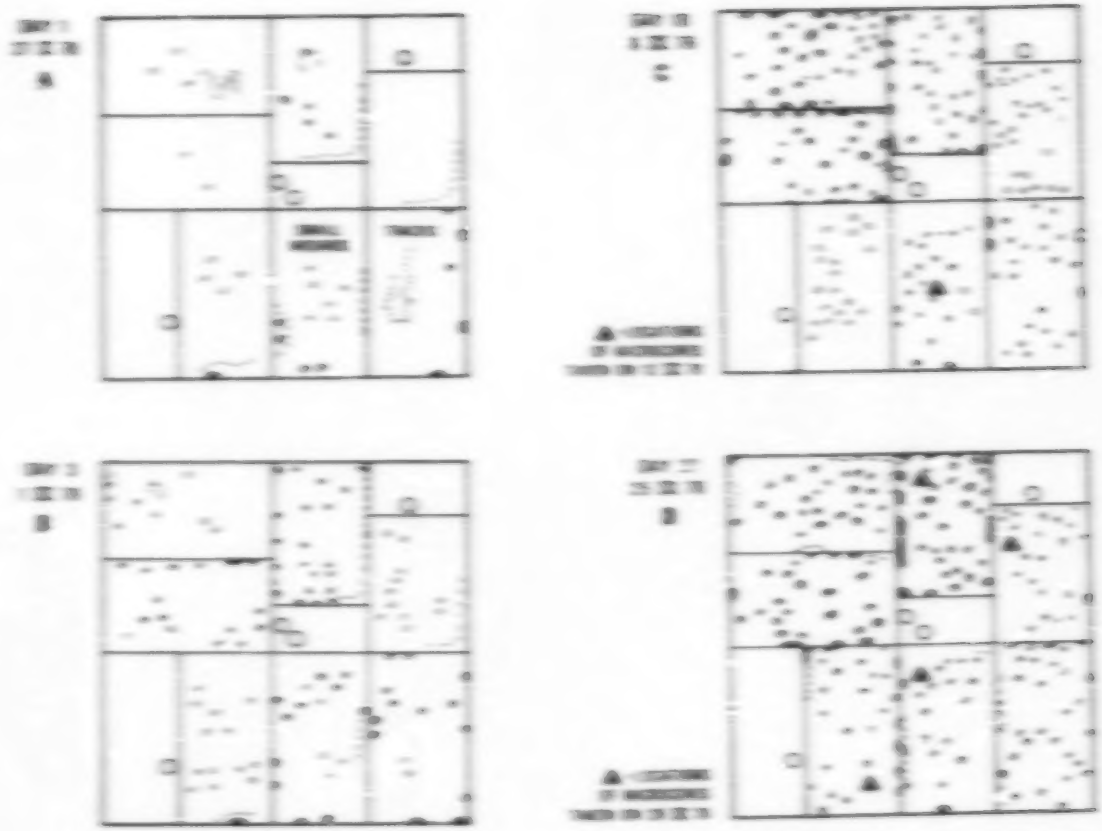

Figure 10. Sketch of Algoid Burrow Locations at Various Times during the Fuel Pier Sediment Experiment. Micro-core Locations also Shown (see text for description)

all trays were occupied by shrimp; thus, micro-topographic features were completely masked. Also on day-27, the E/M was fitted with an opaque cover and supplied with water from an LRT-box (see Section 4). The number of burrow entrances (Figure 10D) per tray were determined as follows:

Tray #1	30	Tray #5	35
Tray #2	19	Tray #6	24
Tray #3	27	Tray #7	25
Tray #4	22	TOTAL	182

Since terminal inventory showed 7 *A. mackayi*, distributed about one shrimp per tray, to be resident in the E/M, there are about 26 ±5 burrow entrances per shrimp, or, judging from the surface aspect alone, burrow occupancy can be estimated to be between 3 and 5%. As suggested earlier, intraspecific conflict may be the reason for the relatively uniform distribution of shrimp.

On 28 May, the Fuel Pier E/M run was also terminated. The E/M was dismantled and the sediment screened as described in Section 5. The organisms found are listed in Table 3.

TABLE 3. ORGANISMS FOUND IN FUEL PIER SEDIMENTS AFTER 92 DAYS IN ULUPAU E/M (14.0 l of sediment)

HCZOB #	Organism	Number Found
55110\4303	*Bhawa nodulosa* Day	8
551120	Eunicidae	2
55112061	*Lumbrineris* spp.	5
552108	Orbinitidae	1 A frag.
6483411002	*Alpheus mackayi* Banner & Banner	7
	TOTAL ORGANISMS	23

Two *A. mackayi* only were found in the 7.2 l of sediment screened at the Fuel Pier collection site. These must be subtracted from the total in Table 3. If the 21 organisms are adjusted to a 7.2 l volume, about 11 organisms were found to be resident in Fuel Pier sediments after 92 days at Ulupau. This represents a 5-fold or greater increase in population as opposed to a conservative 10-fold increase seen in the Kokokahi sediments. That some smaller animals are apparently missed in the field screening is shown by the appearance in both E/M runs of annelid mounds within 24 hours of transfer. Screening effort and mesh size were, however, the same in both field and terminal inventories. Repeated experiments to confirm the observed increases in infaunal populations were indeed beyond the stated objectives of the project and, therefore, were not performed.

In the following discussion of nutrients, the Kokokahi sediments are shown to be especially rich in phosphorus, an element demonstrated to be stimulatory to reef communities (13). This fact may have contributed to the larger increases observed for that experimental run. Although further corroboration is necessary, there seems enough evidence to suggest that the

relatively unoccupied sediments of Kaneohe Bay exhibit about a 10-fold increase in resident infauna, when placed in the clean-water environment represented by Ulupau. This increase may result either from enhanced reproduction among organisms already resident or from settlement of new residents out of the supply waters. It may further be suggested that the condition of waters at the collection sites apparently places constraints on infaunal residency. In brief, the transferred nutrient-rich sediments seem to operate like an analogue to an "artificial reef". Furthermore, the behavior of the infaunal communities is the opposite of that observed in transferred fouling panel or wood block communities (12). These latter are more dependent on water column conditions. It is noteworthy that, although expressly sought, no statistically significant increases in nutrient concentration could be detected in the flow-through waters of either E/M experiment despite the presence of nutrient-rich sediments and despite the observed bioturbic activities of the infaunal residents (see following discussion).

These observations are of sufficient interest to substantiate strong recommendations that further transfer experiments using both sediments and fouling panels be performed. Sediments should include those classified as polluted by heavy metals. If similar population increases can be demonstrated with such sediments, presently accepted strictures on the disposition of dredge material would appear to require re-examination. Further study of the inverse response of transferred fouling panels and infaunal residents should produce greater understanding of marine community reactions to various environmental conditions. Such improved understanding should result in better selection of practical bioindicators of water quality.

NUTRIENT ANALYSIS

Water Column Samples

As described in Section 5, samples of inlet and outlet waters were regularly taken during both E/M experiments. These water samples were augmented by surface and bottom collections in the field at the sediment collection sites and at various other locations shown in Figure 1. As stated in Section 4, Ulupau source waters exhibit short-period nutrient "noise" due to combined low-tide, low-surf conditions (Figure 4). Daily nutrient concentrations reported in ug-at/l were therefore averaged over arbitrarily selected 10-day intervals. A plot of the standard error envelope for ammonia-N concentrations in E/M inlet waters is presented in Figure 11. Statistically significant differences are flagged by a delta and accompanying probability statement, placed between the means in question. A significant increase ($P = 0.01$), which is coincident with the insertion of an LRT-box in the supply line to the model-2 E/M, does appear in Figure 11. The decrease ($P = 0.05$), also shown, is not understood. It is probably an artifact of period selection. Real seasonal (and possibly other) variations in the nutrient concentrations of Ulupau supply waters do occur. For instance, a seasonal difference may be seen when mean nutrient concentrations for this experimental series (#7601) are compared with those of another series (#7503) performed in the early fall (Table 4).

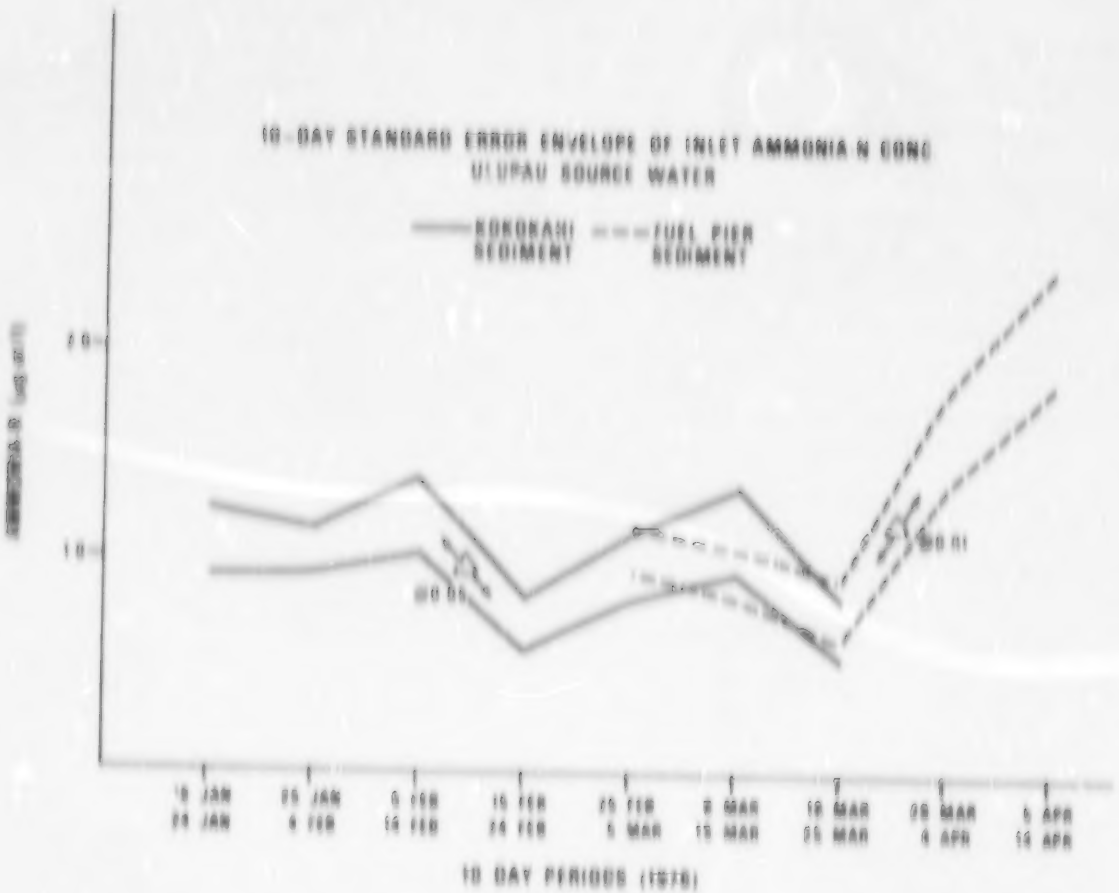

Figure 11. 10-Day Standard-Error Envelope of Inlet Ammonia-N Concentration for Ulupau Source Waters

TABLE 4. SEASONAL CHANGES IN NUTRIENT CONCENTRATION IN ULUPAU SUPPLY WATERS
(mean ± std. error (cases) in ug-at/l)

Nutrient	Ex #7503 Aug-Sep 1975	Ex #7601 Jan 1976	Change (sign. level)
ammonia-N	2.98 ±0.03 (18)	1.07 ±0.14 (18)	0.4x decrease (P = 0.01)
nitrate-N	0.32 ±0.03 (18)	0.98 ±0.16 (18)	3.1x increase (P = 0.01)
phosphate-P	0.11 ±0.01 (18)	0.25 ±0.02 (18)	2.3x increase (P = 0.01)

Except for silica, the short-period "noise" in supply-water nutrients remained reasonably constant, as may be seen from an inspection of the tables of inlet and outlet concentrations given in Appendix A. Except for the short period after the installation of the Kokokahi sediments discussed in Section 5, neither the presence of the sediments nor the addition of shrimp seemed to affect nutrient concentrations in E/M outlet waters. In fact, there was no statistically significant difference between these outlet waters and water samples taken 15 cm above the bottom at the collection sites. Values for ammonia-N are presented in Table 6.

TABLE 6. AMMONIA-N CONCENTRATIONS IN E/M AND FIELD WATER SAMPLES
(mean ± std error (cases) in ug-at/l, Feb-Mar 1976)

	Kokokahi CS*	Sweep Pier	CS & SP*	E/M Outlet
S*	0.65 (1)	0.57 (1)	0.61 ±0.04 (2)	
B*	1.03 (1)	1.05 (1)	1.04 ±0.01 (2)	1.16 ±0.14 (19)
	Fuel Pier CS*			E/M Outlet
S	2.44 ±0.57 (3)			
B	0.91 ±0.13 (3)			0.92 ±0.08 (35)
	Pearl Harbor Alpha Docks	Hospital Pt.	Merry Pt.	all Pearl Harbor
S	3.64 ±1.21 (2)	5.94 ±1.62 (2)	3.78 (1)	4.59 ±0.85 (5)
B	1.55 ±0.07 (2)	2.77 ±0.34 (2)	0.81 (1)	1.89 ±0.40 (5)

* B = sample 15 cm above the bottom; CS = collection site; S = sample 15 cm below surface; SP = Sweep Pier.

The similarity in nutrient concentrations between E/M outlet waters and samples collected 15 cm above the bottom suggests that the sediment-to-water exchange rates in the E/Ms approximate steady state conditions at the collection sites.

There was, however, a significant difference ($P = 0.01$) between surface and bottom ammonia-N concentrations at Fuel Pier and at all locations in Pearl Harbor. Generally, the surface ammonia-N concentrations were about 2½-fold greater. This trend was apparently reversed at Kokokahi and Sweep Pier. The other nutrients (nitrate-N and phosphate-P) did not show surface-to-bottom differences.

Both surface and bottom ammonia-N concentrations in Pearl Harbor were greater than in Kaneohe Bay ($P = 0.05$ or 0.01 depending on which means are compared). With the exception of bottom phosphate, nitrate-N and phosphate-P concentrations were approximately the same in both harbors. The 3 bottom-water samples from Kaneohe Bay showed about twice ($P = 0.01$) the phosphate-P concentration that was found in the 6 bottom-water samples taken in Pearl Harbor. In view of the small number of samples and the larger phosphate concentrations normally reported for Pearl Harbor (17), this observation may not be generally true for the two harbors. The proximity of the Kokokahi collection site to the sewer outfall (see following discussion of micro-core results) may explain the higher bottom phosphate-P values found in Kaneohe Bay.

Micro-core Samples

A total of 22 micro-cores were made: 8 in Kaneohe Bay, 6 in Pearl Harbor, and 4 in each of the 2 E/M runs (see Figures 1, 8, and 10 for locations). Since microcoring technique was investigatory in nature, cores were sectioned in accordance with obvious differences in sediment color, grain size, or biological activity. Although there were indications of elevated nutrient losses from surface layers, variations in sectioning rendered comparisons between field and E/M micro-cores inconclusive. Loss of nutrients from surface-layer interstitial waters ought to be more pronounced in the E/M than in the field, since flow-through waters are lower in nutrient content and since burrowing activity per unit surface area is more intense. No statistically significant differences, however, were observed. For instance, calculated* ammonia-N content (ug-at in 33 ml of sediment) of the top 8 cm were:

Kokokahi site 2.14 ±0.82 (3) Kokokahi E/M 1.36 ±0.27 (4)
Fuel Pier site 1.26 ±0.54 (2) Fuel Pier E/M 0.58 ±0.14 (4).

The same was true for the other nutrients measured. Some typical micro-core results are presented in Figures 12 through 14.

A summary of ammonia-N data for all micro-cores is presented in Table 6 on the following page. In Table 6, ammonia-N content has been calculated* for a section volume of 21 ml; interstitial concentrations were those observed for the full section. Ammonia-N most consistently showed an increase in concentration with depth. The other nutrients showed no consistent trends.

* Ammonia-N content had to be calculated due to variable length of core sections. The volume of an 8 cm length of micro-core is 33 ml; that of a 5 cm length is 21 ml.

Figure 12. Typical Kokokahi Field and E/M Micro-cores

Figure 13. Typical Fuel Pier Field and E/M Micro-cores

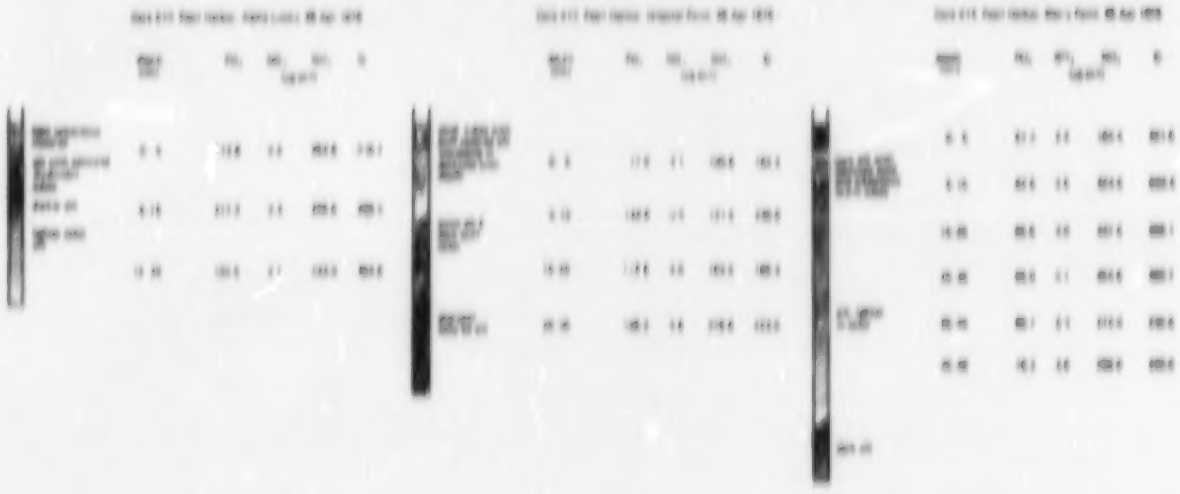

Figure 14. Typical Pearl Harbor Micro-cores

TABLE 6. CALCULATED AMMONIA-N CONTENT AND (OBSERVED INTERSTITIAL CONCENTRATION) FOR VARIOUS MICRO-CORE LAYERS
(content = ug-at in 21 ml; concentration = ug-at/l)

Core # & Descrp.*	0 to 5 cm		15 to 20 cm		25 to 30	
3 Sweep, Fld	-	(39.6)	0.45	(108.9)	1.67	(99.0)
4 FP, Fld	0.43	(47.9)	-	(-)	-	(-)
5 FP, Fld	1.14	(97.4)	0.89	(178.2)	0.38	(128.7)
6 Kk, Fld	2.34	(-)	-	(-)	-	(-)
7 Kk, Fld	1.03	(154.8)	1.23	(180.0)	1.34	(239.4)
8 Kk, Fld	0.75	(86.9)	1.09	(156.8)	0.72	(158.4)
9 Alpha, P.H.	0.66	(63.9)	0.92	(157.5)	0.78	(117.0)
10 Alpha, P.H.	2.63	(252.9)	2.49	(333.0)	-	(-)
11 Hosp. Pt. P.H.	0.55	(65.7)	0.35	(44.1)	1.28	(256.5)
12 Hosp. Pt. P.H.	0.80	(100.8)	1.17	(193.5)	1.74	(279.9)
13 Merry Pt. P.H.	2.22	(280.9)	2.76	(311.4)	3.04	(417.6)
14 Merry Pt. P.H.	1.50	(194.4)	2.24	(337.5)	1.24	(364.6)
1 Kk, E/M, B-1	-	(77.4)	-	(-)	-	(-)
15 Kk, E/M, B-1	0.46	(60.1)	-	(-)	-	(-)
16 Kk, E/M, B-2	0.40	(53.5)	-	(-)	-	(-)
17 Kk, E/M, B-6	0.35	(40.1)	-	(-)	-	(-)
18 Kk, E/M, B-8	0.41	(49.8)	-	(-)	-	(-)
2 FP, E/M, T-2	-	(46.0)	-	(-)	-	(-)
19 FP, E/M, T-2	0.43	(57.1)	-	(-)	-	(-)
20 FP, E/M, T-3	0.50	(54.7)	-	(-)	-	(-)
21 FP, E/M, T-4	0.16	(15.8)	-	(-)	-	(-)
22 FP, E/M, T-5	0.14	(15.7)	-	(-)	-	(-)

* Cores numbered sequentially according to date of sample; B = bucket; Fld = field sample; FP = Fuel Pier; Hosp. Pt = Hospital Point; Kk = Kokokahi; P.H. = Pearl Harbor; Sweep = Sweep Pier; T = tray.

The average interstitial concentrations for the 4 nutrients measured are presented in Table 7 on following page. Where the standard deviation was greater than half the mean, the value is followed by a "V". These large variations were usually caused by low surface-layer values or a single high value somewhere in the core sections. Pearl Harbor cores were higher in ammonia-N and nitrate-N than field samples from Kaneohe Bay, but lower in phosphate-P. As reported above, lower phosphate-P concentrations were also found in bottom-water samples from Pearl Harbor. Although samples varied considerably, the highest average phosphate-P values were observed in the Kokokahi sediments. Perhaps these elevated concentrations are due to the proximity of the collection site to the sewer outfall. Apparently, the sediments lost phosphate-P but gained nitrate-N during their 92- and 135-day exposures in the Ulupau E/Ms. Further work using the micro-coring technique would be required to substantiate these trends.

TABLE 7. MEAN NUTRIENT CONCENTRATION IN MICRO-CORE INTERSTITIAL WATERS
(ug-at/l; V = std. deviation greater than half the mean)

Core # & Descrp.*	phosphate-P	nitrate-N	ammonia-N	silicate-Si
3 Sweep, Fld	146. V	1.58	122.	308.
4 FP, Fld	250. V	1.40	61.1	606.
5 FP, Fld	78.2	1.50	141.	426. V
6 Kk, Fld	432.	9.0	239.	390.
7 Kk, Fld	371.	7.70 V	191.	495.
8 Kk, Fld	45.7 V	1.63 V	122.	276. V
9 Alpha, P.H.	27.5 V	4.65 V	120.	389. V
10 Alpha, P.H.	144.	2.93	280.	299.
11 Hosp. Pt, P.H.	32.8	2.68	103. V	136. V
12 Hosp. Pt, P.H.	114.	4.58	174.	255.
13 Merry Pt, P.H.	185.	2.08	312.	372.
14 Merry Pt, P.H.	81.8	3.17	306.	381. V
1 Kk, E/M, B-1	-	-	77.4	-
15 Kk, E/M, B-1	5.20	3.70	159. V	142. V
16 Kk, E/M, B-2	4.47	6.37	89.9	83.8
17 Kk, E/M, B-6	2.43	4.23	169. V	130. V
18 Kk, E/M, B-6	3.48	5.45	105.	164.
2 FP, E/M, T-2	-	-	48.0 V	-
19 FP, E/M, T-2	14.4	4.55	37.6	-
20 FP, E/M, T-3	14.4	4.95	60.8	-
21 FP, E/M, T-4	15.6	6.30 V	16.6	-
22 FP, E/M, T-5	9.60	4.50	63.2 V	-

* see Table 6 for key.

Elutriation Test

Samples of sediment were collected and subjected to the standard elutriation test in accordance with U.S. Army Corps of Engineers procedures (Section 5). The results of these tests and the analysis of the diluent waters are presented in Table 8 on the following page. As may be seen, the amounts of phosphate-P, ammonia-N, and silicate-Si released by both Kokokahi and Fuel Pier sediments are well in excess of 1.5-fold greater than that found in Ulupau source waters. Values range from 3-fold to almost 30-fold. According to the criterion of the Environmental Protection Agency and the Corps of Engineers, these sediments would be classified as polluted in phosphate, ammonia, and silicate. However, in the authors' opinions, the term "nutrient-rich" is to be preferred.

Comparison of elutriation test and micro-core analyses produces interesting results. To enable such comparison, the nutrient release values (R) from the elutriation test must be corrected (corr.f). This is done by subtracting the ambient concentration of a given nutrient in Ulupau source water from that released from the sediment and then multiplying by 5 to correct for the 1-to-4 dilution. The resulting value should approximate

the mean concentration of that nutrient in the interstitial waters of the tested sediment. The mean micro-core values were obtained by averaging data presented in Table 7. With the exception of nitrate-N, corr.E and E/M micro-core values show good correspondence. Field micro-core values, however, show striking differences, especially so for phosphate-P. They suggest that enhanced release of nutrients, similar to that brought about by the standard elutriation test, is occurring in the E/Ms.

TABLE 8. NUTRIENT RELEASES ON STANDARD ELUTRIATION TEST AND COMPARISON WITH MICRO-CORE RESULTS
(ug-at/l; mean ± std. error for 4 replicates)

CS/test*	phosphate-P	nitrate-N	ammonia-N	silicate-Si
Kk, R	1.08 ±0.02	0.66 ±0.15	27.9 ±1.34	51.8 ±10.9
FP, R	2.53 ±0.07	0.63 ±0.51	10.0 ±0.39	46.9 ±2.67
UI	0.32 ±0.04	0.48 ±0.14	0.96±0.22	12.3 ±13.1
ratio: R/UI	3x to 8x	1.3x to 1.4x	10x to 20x	4x
Kk, corr.E	3.8	0.90	136.	197.
Kk, E/M cores	3.9 ±1.2	4.7 ±0.9	126. ±53.	127. ±31.
Kk, Fld cores	283. ±208.	6.1 ±4.0	184. ±59.	387. ±110.
FP, corr.E	11.0	0.78	45.4	172.
FP, E/M cores	13.5 ±2.7	5.1 ±0.8	45.2 ±19.	-
Fp, Fld cores	164. ±121.	1.4 ±0.1	96.0 ±63.	560. ±190.

* corr.E = corrected elutriation test (see text); CS = collection site; R = released nutrient concentration; UI = Ulupau inlet waters; see Table 6 for rest of key.

For ammonia-N at least, the decrease in interstitial water concentrations as the sediment surface is approached implies either enhanced surface exchange or bacterial regeneration. The latter activity might also explain the phosphate loses and nitrate gains suggested by the E/M micro-cores. Evidently, due to currents or diffusion, neither exchange rates nor the effect of bioturbic activity upon such rates can be measured with the water-column techniques used. Further use of micro-cores and measurement of nutrient concentration in the burrow-tunnel waters suggest themselves as good potential means of making such determinations.

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APPENDIX A

NUTRIENT LEVELS IN E/M FLOW-THROUGH WATERS

Ulupau source waters exhibit short-period nutrient "noise" due to combined low-tide, low-surf conditions. Nutrient levels tabulated below are therefore presented as means for the following 10-day intervals:

Period A	15 Jan - 24 Jan 1976	
" B	25 Jan - 4 Feb	"
" C	5 Feb - 14 Feb	"
" D	15 Feb - 24 Feb	"
" E	25 Feb - 5 Mar	"
" F	6 Mar - 15 Mar	"
" G	16 Mar - 25 Mar	"
" H	26 Mar - 4 Apr	"
" I	5 Apr - 14 Apr	"

All values are reported in ug-at/liter of the element, using the format: mean ± standard error (number of measurements). Waters flowing into an E/M or inlet water are marked by the symbol "I"; waters flowing out or outlet waters are marked "O". The standard error envelope for inlet ammonia-N concentrations given in Table A-1 are presented in Figure 11 of the text.

TABLE A-1. AMMONIA-N CONCENTRATIONS FOR ULUPAU E/M WATERS
(µg-at/l; mean ± std. error (cases); I = inlet, O = outlet)

Period		Kokokahi Sediments		Fuel Pier Sediments	
A	I	1.10 ±0.16 (15)			
	O	1.01 ±0.11 (15)			
B	I	1.05 ±0.13 (12)			
	O	1.09 ±0.10 (12)			
C	I	1.20 ±0.19 (13)			
	O	1.10 ±0.11 (13)			
D	I	0.70 ±0.12 (10)			
	O	0.69 ±0.06 (10)			
E	I	0.97 ±0.16 (9)		I	1.06 ±0.11 (12)
	O	1.34 ±0.18 (9)		O	1.11 ±0.15 (12)
F	I	1.16 ±0.20 (4)		I	0.95 ±0.12 (11)
	O	0.84 ±0.22 (4)		O	1.06 ±0.14 (11)

(continued)

TABLE A-1. (continued)

Period	Kokokahi Sediments	Fuel Pier Sediments
G	I 0.69 ±0.14 (6) O 1.08 ±0.31 (6)	I 0.77 ±0.15 (12) O 0.65 ±0.08 (13)
H		I 1.61 ±0.23 (7) O 2.33 ±0.24 (13)
I		I 2.14 ±0.26 (6) O 2.49 ±0.28 (14)

TABLE A-2. NITRATE-N CONCENTRATIONS FOR ULUPAU I/H WATERS
(ug-at/l; mean ± std. error (cases); I = inlet, O = outlet)

Period	Kokokahi Sediments	Fuel Pier Sediments
A	I 0.92 ±0.16 (15) O 0.76 ±0.16 (15)	
B	I 1.29 ±0.56 (3) O 0.88 ±0.32 (3)	
F	I 0.49 ±0.21 (3) O 0.13 ±0.02 (3)	I 0.60 ±0.23 (7) O 0.29 ±0.05 (7)
G	I 0.24 ±0.02 (6) O 0.28 ±0.10 (6)	I 0.34 ±0.04 (12) O 0.29 ±0.05 (13)

TABLE A-3. PHOSPHATE-P CONCENTRATIONS FOR ULUPAU I/H WATERS
(ug-at/l; mean ± std. error (cases); I = inlet, O = outlet)

Period	Kokokahi Sediments	Fuel Pier Sediments
A	I 0.25 ±0.02 (15) O 0.22 ±0.02 (15)	
B	I 0.25 ±0.02 (3) O 0.25 ±0.03 (3)	
F	I 0.15 ±0.06 (3) O 0.17 ±0.02 (3)	I 0.11 ±0.02 (7) O 0.18 ±0.03 (7)
G	I 0.76 ±0.52 (6) O 0.59 ±0.24 (6)	I 0.29 ±0.07 (12) O 0.54 ±0.27 (13)

TABLE A-4. SILICATE-SI CONCENTRATIONS FOR ULUPAU E/M WATERS
(ug-at/l; mean ± std. error (cases); I = inlet, O= outlet)

Period	Kokokahi Sediments	Fuel Pier Sediments
B	I 10.66 ±4.64 (9) O 3.58 ±0.34 (9)	
C	I 12.72 ±6.70 (7) O 9.29 ±4.54 (7)	
H		I 6.29 ±1.49 (6) O 7.69 ±1.07 (11)
I		I 7.57 ±1.19 (6) O 7.67 ±1.16 (14)